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ABSTRACT

This paper describes an experimental approach to teaching PSSC Physics by using, whenever possible and proper, behavioral and social analogies as illustrations for physical concepts. The report is based on several years of use of this experimental program. The developers consider the preliminary findings to be encouraging. Student enrollment has increased as have student interest and scores on objective tests. (Author/PEB)

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Social Examples in Teaching Physical Concepts

Dr. Gideon O. Hirsch

This paper describes an experimental approach to teaching PSSC Physics by using, whenever possible and proper, behavioral or social analogies as illustrations for physical concepts. Efforts were made to avoid discussions "about science", to distinguish between science and technology and to concentrate on science itself, undiluted. The experiment is now in its third year.

The preliminary results are very encouraging: students enrollment doubled and tripled, students interest borders on enthusiam, outstanding success in objective tests accross the board.

Introduction

The flight from science was described and analysed in many papers. One may add to Paul Westmeyer's[1] revealing list of its causes the unpleasant observation that we teach "old stuff". High school physics and chemistry are almost exclusively 18th and 19th century science. Liberal arts oriented students have absorbed, mostly from the media, sufficient amount of half truths and stories "about" scientific facts to get the impression that they already know as much as they care to know about science, and that it's a boring "dead subject" anyway.

Another cause might be, ironically, the notion that science is deterministic and even indoctrinary. In spite of the investigative approach-the student is left with the notion of one correct answer and one predetermined result. Students who vigorously oppose those concepts in political and social life would subconsciously resent science in principle. A magic cure to this symptom is found in philosophical discussion of duality, special relativity and uncertainty, but as long as they are kept out of the curriculum - one must resort to talk "about" them.[2] The main cause for the flight from science, particularly of the bright, involved, alert and sensitive students, remains however the issue of relevance. When students were asked to mention

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three questions they most desire answers for, their questions were behavioral, social or philosophical. No one really cared why the accelerated electron does not radiate or what holds protons together. Paul Westmeyer says "Ought we then find out somehow how students live and then design curricula to show them how science is relevant in their daily activities? This too, has been tried and it also misses the boat. Science is NOT particularly relevant in the daily lives of most people, especially students." As if we have here a new generation of Athenian Aristocrats[3], who know their existence depends on the results of science, as on manual labor, but who are ready to pay someone to do these tedious jobs for them, so they are free to deal with more beautiful and more rewarding subjects. If this is indeed so, we would probably continue to flavor science more and more, like flavoring unpleasant drug, and insist its cultural value mandates keeping it as an education requirement - until it will become another Latin in our schools.

The driving force for this experimental approach was the conviction (and fear!) that we have no right to impose on a young person the wasting of his time, energy and goodwill on an irrelevant course. An attempt was made to show applicability of ideas and concepts to behavioral and social phenomena. Some were suggestive analogies. Some were fully developed models. The examples below follow the actual language used in the classroom.

Suggestive Analogies

1. Electrical induction and the Field concept.

   What is love? Something happens to you because of the presence of another person. Sure you would like to interact with that person, at least touch hands, but you touched hands many times before, without that pleasant sensation. So it's not the touching. It's not even necessary. The mere knowledge of him or her existing near you, and caring about you, does cause this effect. Now let's examine electrostatic induction..... something happens to this steel ball when in the presence of a charge, they don't have to touch. There is no push. But the ball "feels" the field. The field is invisible, but we know it is there because the

ball responds to it and undergoes changes, "why do I love you? I love you not only for what you are, but also for what I am, when I am with you".

2. Simple harmonic motion.

There is one point called "happiness", one position or situation we desire. The further away we are from it-the larger our effort to reach it. Effort always directed towards it, wherever we are. When we reach that point-that effort is zero but our "momentum" carries us away. And again we develop this force now in the opposite direction. Social literature, particularly in Europe, is many times like that: pushing to the left, learning the country went too much to the left, now pushing th the right...Even governments oscillate that way. If there is friction - the system will oscillate around its desired value for a while, until it stops, like a bouncing ball finding the ground or a new stock on the exchange finding its proper price. If there is no friction-SHM is really an exercise in futility.

3. The structure of the atom.

The cubist movement in painting claimed objects are really empty, and we can see their inside thru their walls. Furthermore, all objects are made of different combinations of three basic elements: cube, cone and sphere, no matter how different these objects seem to be. Remember the Rutherford atom (empty space) and its elements (n,p,e)? Is it a mere coincidence? Check the dates! (Idea after Waddington).

SUGGESTIVE MODELS

1. Kinematics

Let's look at figure 1, describing the rate of reported violent crimes in a certain city $\vec{v}$ (measured in number of crimes per week) versus the time from the beginning of the year $\vec{t}$ (measured in weeks). In spite of the fluctuations, it looks almost like a straight line. What can we learn from that graph at a particular moment, say $t=12$ (the end of the twelfth weeks)? Obviously, the value of $\vec{v}$ at that moment, $v=135$ crimes/week. But we also see the TREND: since the beginning of the year ($t=0$ $v=120$ crimes/week),

FIGURES 1-4: THE RATE OF CRIME IN A CITY SINCE JANUARY 1, 1972

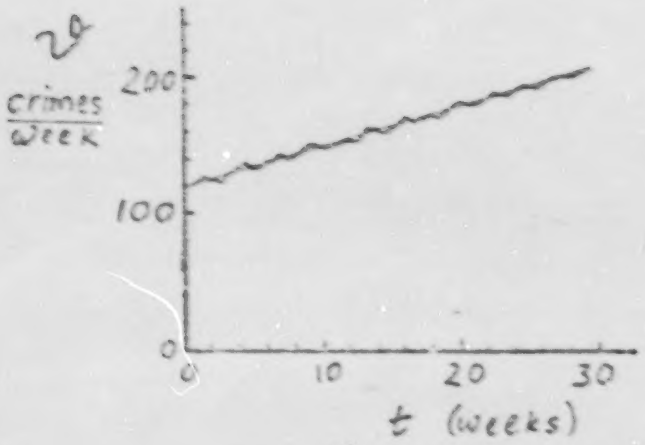

fig 1

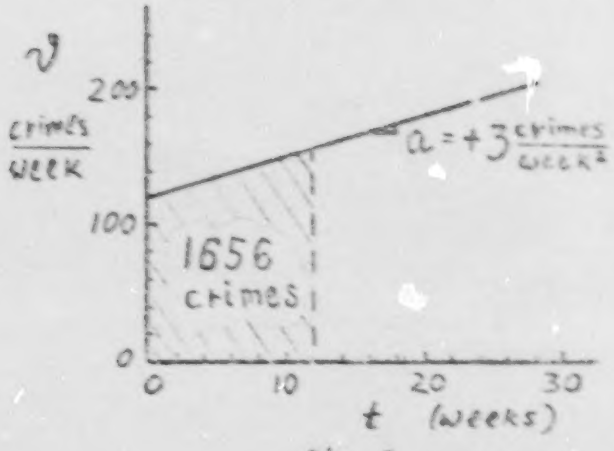

fig 2

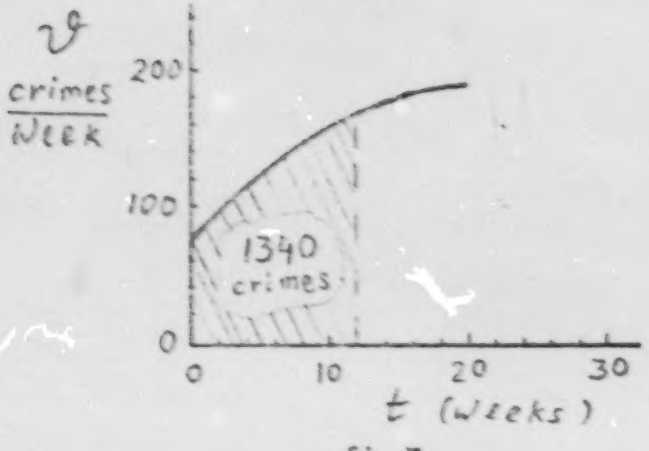

fig 3

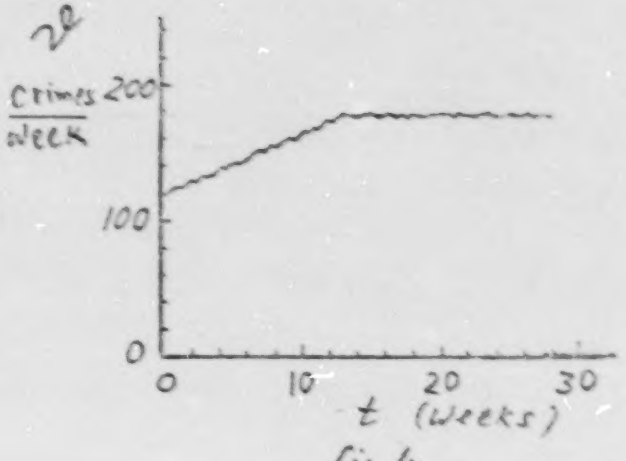

fig 4

fig 5

fig 6

FIGURES 5-6: LEARNING ACHIEVEMENTS IN SCHOOL

during $\Delta t = 12$ weeks there was an increase in violence of $\Delta v = 36$ crimes/week, or an average increase in crime of 3 times/week every week. We call it "trend" because if it will continue the violence next week will be 159 crimes/week, and in the t'e week

$$v = 120 + 3t \quad .$$

The "trend" the slop of v, represents the rate of change of v, is also called "acceleration", a and its unit "crimes/week every week" can be written in brief "crimes/week^2". In general, therefore, $v = v_0 + at$.

Figure 1 gives us additional information about $t = 12$. The area under the graph, up to this point, represents the total number of crimes committed that year until $t = 12$. In this case 1656 crimes. It can be verified by adding $120+123+126+\cdots\cdots$

but one can easily see that the trend is constant thruout the whole time interval, hence, the total could be correctly calculated by using an average value $\bar{v}$. The value of v at both extremes of this time interval are 120 and 156, hence $\bar{v} = 138$ crimes/week, or $\bar{v} = \frac{1}{2}(v_0 + v)$. The total "disaster" d, the total number of crimes between $t = 0$ and $t = 12$ is therefore $138 \times 12 = 1656$ crimes, or generally

$$d = \bar{v} \cdot \Delta t = \tfrac{1}{2}(v_0 + v)\, t = \tfrac{1}{2}(2v_0 + at)\, t = v_0 t + \tfrac{1}{2} a t^2 .$$

Hence, to find d you have three alternatives: you may use this formula, or find the average rate of crime $\bar{v}$ and multiply it by the time interval, or find the area of the trapezoid in the proper units in which it is represented.

In summary: Figure 1 gives us plenty of information about the crime situation at any given time. The VALUE OF v itself gives us the present, the actual value of v at the moment. The AREA under v gives us the cumulative past, the total disaster up to that time. The slope of v gives us the trend, the ability to predict the future. See figure 2. Sometimes the graph of v against t is not a straight line.

In such case the "trend"varies from time to time. In figure 3, for example, the trend near t=0 is about 10 crimes/week every week; near t=7, the trend is about 6 crimes/week^2 and at t=12 it is 3 crimes/week^2. A citizen observingfigure 3 might feel happy, because the rate of crime is "leveling off":violence occurs more than ever before, but its acceleration is reduced and maybein the near future, be eliminated or even become negative. Obviously, one cannot single out any particular $\underline{a}$ (acceleration) for the whole system, hence none of the helping equations above is applicable here. The rest, however, is fully valid. The area represents the cumulative past, and the (momentary) slope, or tangent, represents the (momentary) trend for the future.

Even though the general case looks like figure 3 - some portions of it are sufficiently close to straight lines, each resembling figure 2, Thus the equations we derived can be very helpful in many practical cases. It is important to remember, however, that the equations are NOT the phenomenon; they are merely a short calculation method. The phenomenon is equally described by the graph. Same type of graph may describe the variation with time of many other "rate" phenomena, like rates of births, of coal production, of college attendance or of distance travelled by a moving object. The $\underline{v}$ in each of these cases is the (momentary , actual)rate, the $\underline{a}$ is the trend of change of that rate, and the $\underline{d}$ the total accomplishment of the phenomena, up to any given time. Using an average $\underline{a}$ (or if $\underline{a}$ is more or less constant), one may use the equations

$$v = v_0 + at$$
$$d = v_0 t + \tfrac{1}{2} a t^2$$

as a short method of calculation for each and any of these phenomena. The equation,like the graph,merely describe the phenomena without saying a word about its reasons.

2. Causing change

Examine figure 4. What could have happend on April 1, the end of the 13th week of the year? The crime situation obviously has two distinctive patterns: up to that date, it accelerated $\underline{a}$=3 crimes/week^2; beyond that date, it suddenly"leveled off ", maintaining $\underline{a}$=0 or a constant rate of $\underline{v}$. Something must have happened on that date. What do you suggest? (A vivid discussion usually follows, with imaginative contributions even from

the slow learners. Like: A new Mayor was elected who cracks down on crime; more policemen on the job; policeman started to get real serious and work hard or; criminals got lazy, criminals left for vacations, etc.) The suggestions can be summarized by "Police made more effort", or by "criminals reduced their effort" or by a combination of both. Let F stand for "effort" with positive or negative directions, depending if it helps or disturbs crime. Anywhere during the first 13 weeks, both F_p and F_c existed, but F_c (the effort of the criminals) was stronger. Hence $F_c - F_p > 0$ or: $F_{net} > 0$. There was a "net effort" towards the increase in crime, and this is probably responsible for the acceleration $a = 3$ crimes/week^2. However, starting with the 14th week $F_c = F_p$ or $F_{net} = 0$, there was no "net effort", hence there was no change in the rate of crime.

During this period, many crimes were committed (from figure 4:150 crimes every week), crime was not eliminated. But the acceleration, the change in the rate of crime, was eliminated, thanks to the balance of the efforts of the criminals and of the police. Equilibrium, or balance, results in "no change". Many facets of life exhibit "steady" situations, where no "net change" occurs. In each such situation, the "net effort", net force or net flow is zero. Examples are financial earning and spending (if balanced - no change in savings), input and output of flow of liquid to/from a tank (if balanced-no change in liquid level of the tank), supply and demand, the concept of "zero population growth".[6] If there was a "net effort" - it would tilt the system out of balance.

Thus the change in the system, a, is very sensitive to F_{net}, the net effort which throws the system out of balance. Obviously, the direction of the change will be that of the net effort causing it. Wouldn't it be nice if the magnitude of the change, the effect, be proportional to its cause?

In many cases, nature indeed behaves that way, giving

effect = (constant) cause

where the "cause" is obviously the "net effort". Thus, in figure 2, for example, if the

balance of effort would shift (by decrease in police effort, or increase in criminals effort, or both) so that the new net effort would be twice as much as it is now - you would expect the rate of increase of crime to double, hence a would be +8 crimes/week^2.
Comparing the action of same cause on different objects or systems we must take their "inertia" into consideration. By inertia we mean " passive resistance to change" kind of "lazyness, sluggishness, difficulty to change"
As young people you experience "change" every month, in almost every facet of life: Your height, weight, appearance, choice of friends, clothes, polical opinion, music, books, travel, girl or boy friend, and many many more. You observe that adults as individuals, experience much less change than you do - and even less as a society.
Some of you begin to cherish "change" as a value and have impatience or even contempt to the "inability" of adults to change. [A1] If they have very large inertia, so a very strong cause is needed to produce even a small effect of change. It will be valuable therefore, to closely examine the whole phenomena.
The same "net effort" or cause, may result in significant change in you - but much smaller change in your parents. You may say that their "habits" are strong, firm, well established - so their "difficulty" to change is much larger than yours. Is it really so bad? If you meet a girl you like more than your current girl friend - you change your girl friend, without too much fanfare. But your father will not be able to do it that easily: he has social and financial commitments to his wife and children, and some of this social or even business activities are tied up to your mother. All this network may seem to him as a "burden" when this new woman appears, whereas your "burden" is much lighter. He might change a little some of his behavior, as a result of this F_{net}, but his change will be much smaller than yours. So "inertia" attempts to preserve the prevailing order, so the system will not go astray with every accidental force or erratic wind. To find the result, the effect, of a cause, an effort, you must compare the magnitude of the "net cause" to the magnitude of the "inertia" of the system. The ratio between the two will indicate the size of the effect.

It is important to distinguish between "active resistance" and "passive resistance". The latter is exactly the inertia, whereas the former is one of the components making the "net effort", usually in a negative direction, to reduce its size. Thus the overall activities of the criminals, of the police and of other interested parties, each in its own direction, together will make the "net effort" toward changes in the crime situation. Weather conditions, mobility on the streets, cooperation of the general public, will be the inertia. The ratio between the two will yield the "effect".

3. Dynamics

The general equation resulting from the above discussion is

$$\text{change} = (\text{constant}) \cdot \frac{\text{net effort}}{\text{inertia}}$$

and with the proper choice of units for the variables, one may even drop the constant.

Using the symbol m for inertia (it seems the more massive an object is-the more inertia it has) and a for change, we get

$$a = \frac{F_{net}}{m}$$

The fundamental difference between this equation and say, $d = v_0 t + 1/2\ a\ t^2$, gives us an opportunity to get some insight into what physics is all about[5]. Is "velocity" physics? Not more than inflation, the rate of crime, or the rate of birth. All are measurable, can be plotted, described by graph or even by equations. Each such equation will be a descriptive equation, using variable of only one "quality", all from the same ball game. Those equations are really mathematical models of the phenomena, and have very little to do with physics[6].

On the other hand $a = \frac{F_{net}}{m}$ is like a bridge connecting two continents: the world of forces and the world of motion (or crime, inflation etc.) It has one carefully chosen representative from each world and finds the relation between them, for every particular system of inertia m. This is physics: describing (and predicting) the interrelations between variables of different qualities. Is Psychology physics? After all it does try to relate cause and effect. Can social/behavioral/political sciences be also considered physics? They all are on their way. They all are in the stage of gathering data, defining and seperating the variables and attempting to measure them and fit mathematical models for them. A stage very similar to the refractive behavior of light before Snell or to astronomy before Kepler. Physics is so far ahead of the other sciences because it deals with relatively simple systems, which can be easily isolated, where variables are separable and measurable, and most important, where identical experiments can be repeated yielding identical results, to solidly confirm or deny any suggested hypothesis or theory. It seems that experimentally confirmed theories are really the essence of physics. The above mentioned sciences have a long way to go in order to reach, if ever, the same state. But particular theories or systems from physics could serve as helpful models for these sciences.

Let's discuss Education for example. A kid can learn on his own, by everyday's experience now and then, but society built schools and pays teachers in a special effort to make him learn systematically and effectively. If he successfully masters the knowledge and skills taught him last week (measured in arbitrary units per week) he will be able to learn more the next week, as he is more knowledgable and skillful. So the result of the special effort is the increase in the rate of the acquired knowledge. Seems like simple relation between "effort" F net and "change" a (the trend in figure 5,), very much like the above equation $a = \frac{F_{net}}{m}$

This is the setting. Now let's discuss a problem.

Experience shows two groups of kids, significantly different in their achievements. A characteristic description is given in figure 6, which can be reduced to the mathematical model: $v_p = 30 + 12\,t$ $\qquad$ $v_u = 30 + 6\,t$

for the privileged and unprivileged child, respectively; t is the number of years in school, v is the rate of acquiring knowledge in arbitrary units per week. It is assumed that both groups enter school with the same initial rate of acquiring knowledge v_0 resulting from childhood experience.

Obviously, the privileged child is getting much more education than the unprivileged child. In an attempt to improve the situation came Head Start and gave the underprivileged child some pre-school education, as described in figure 6, to enter school at an initial v_0 of say 55 rather than 30. All went well for a few years - until the poor child starts lagging again, say from the fifth grade on. What went wrong? How could the same effort produce such unequal results? How can it be corrected?

Physics would isolate from figure 6, or from the equations, the values of the trends for each child $a_p = 12$ $\qquad$ $a_u = 6$ (units per week per year), The effort made by the school is indeed the same in each case, say 60 units of effort. A probable explanation for the different results in school, might be found by the hypothesis that the suggested relation between cause and effect, namely $a = \frac{F_{net}}{m}$ is valid in this case. By putting the data of a and F_{net} for each child one finds their inertias:

$m_p = 5$ $\qquad$ $m_u = 10$

(in units of inertia). Hence it is the inertia of the unprivileged kid which seems to be the root of the problem, not his v_0. Head Start took care of the symptom, the v_0, rather than of the root. How should the situation be corrected?

Well, physics does not solve socio-political problems. It only can illuminate them. If the model is right, physics can say that you have to define the term "equal opportunity". Then - if it means "equal effort for each child", say equal school budget per pupil, then the differences in educational results is here to stay. But - if it means "sufficient outside

effort to provide equal results", then the school's effort for the underprivileged must be increased. In the particular example above, the underprivileged kid needs exactly twice the effort given to the other, in order to show same results (same rate of change).. It might be interesting to mention that the gravitation of mother Earth gives all objects "equal opportunity" which is not "equal force" but "the necessary force for equal acceleration".

Results of the Experimental Approach

1. Enrollment. Students are free to choose physics in the 11th or 12th year. The size of the graduating class in all years was around 120-130 students. Of these, the percent of students electing physics

Five years to 1969	1969-70	1970-71	1971-72	1972-73
10-13%	12%	15%	30%	36%

2. Percent of girls in physics classes increasedsignificantly.
3. Rate of dropping out,in the middle of the course,was decreased almost to zero.
4. Passing New York State Regents examinations in physics, and the mark of the median student in the class:

	Five years to 1969	1969-70	1970-71	1971-72
Students Passing	75-88%	87%	100%	100%
Medians	N.A.	78	90	86

5. Feedback from college: the graduates of this approach claim they seem to understand science somewhat more,and enjoy it more,than most of their friends. This is particularly so for students who major in college in liberal arts.
6. There is no way to measure enthusiasm, satisfaction and happiness, but they are there.

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4. Waddington C. H. "Behind Appearance", MIT Press, 1970.

5. See also Lindenfeld, Peter, "Clearly Defined?" The Physics Teacher, Vol. 10, p. 458, 1972.

6. Many more examples can be found in "Limits to Growth", Meadows, et al, Universe Books, 1972.

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